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TABLE OF CONTENTS

Abstract.....	ii
Introduction.....	1
Background.....	1
Virginia Pound Net Fishery	1
Pound Net Regulations to Protect Sea Turtles	2
Gear Research to Protect Turtles	3
Methods.....	5
Data.....	5
Cost Calculations	7
Results.....	8
Discussion	9
Acknowledgements.....	13
References Cited	14

ABSTRACT

A cooperative gear research program was cost-effective compared to a closure to reduce sea turtle (families Cheloniidae and Dermochelyidae) interactions in the Virginia Chesapeake Bay pound net fishery. Commercial fisheries have been subject to closures and gear restrictions to protect sea turtles; the cost of these alternatives can differ greatly. After 4-6 years, the cumulative present value of costs for a gear modification, including research costs, was lower than for a closure; that is, the gear modification was cost-effective relative to the closure. Even for this small fishery, it may be financially prudent for fishermen to invest in gear research if the alternative is a closure. The factors that contributed to these results in the pound net fishery, including cooperative research and availability of observer data, are considered for their application to other fisheries.

INTRODUCTION

All six sea turtles¹ found in the waters of the United States are listed as endangered or threatened under the Endangered Species Act (ESA)². NOAA's National Marine Fisheries Service (NMFS) is jointly responsible with the U.S. Fish and Wildlife Service (FWS) for protection and recovery of sea turtles³, including limits on commercial fisheries to reduce "takes." A "take" under the ESA is to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect an ESA listed species, or to attempt to engage in any such conduct. When a take is due to incidental capture in a commercial fishery it is often describe as bycatch.

The U.S. government has implemented closures to manage interactions between commercial fisheries and sea turtles⁴; however, the economic impact on fishermen may be significant (Curtis and Hicks 2000). This paper provides an example, using the pound net fishery in the Virginia part of Chesapeake Bay, of how a gear modification may provide similar protection for a species at the lower cost; that is, the gear modification is cost-effective relative to the closure. In addition, the difference in present value costs between the two management actions provides an estimate of the economic benefits of cooperative gear research.

Beginning in 2001, some pound net fishermen in the Virginia portion of Chesapeake Bay were required to tie-up or remove their pound net leaders, effectively closing part of the fishery (66 FR 33489). During the course of multiple rule changes, the spatial extent of the closure was decreased while the temporal extent was increase. During 2004 and 2005, cooperative gear research between NMFS and the pound net fishermen resulted in a leader design that appeared to minimize turtle impingement and entanglement. In 2006, a new rule allowed the use of this modified leader (71 FR 36024), and a gear modification was substitute for a closure for turtle protection.

In this paper, we present background information on the Virginia pound net fishery, regulations imposed to protect sea turtles, and the cooperative approach to pound net gear research. The direct costs of the two management alternatives are calculated, and the difference in cumulative costs over time and under alternative assumptions are illustrated. The paper closes with a discussion of factors that may affect the generalizations of these results to other fisheries.

BACKGROUND

Virginia Pound Net Fishery

A pound net is a fixed fishing device that consists of poles or stakes secured into the bottom with netting attached. The structure includes a pound with a netting floor, a heart, and a straight wall or leader (Figure 1). Pound nets are generally set close to shore and the leader is set perpendicular to the shore to guide migrating fish into the pound. In Chesapeake Bay, NMFS regulations differentiate between offshore and near-shore pound nets. When a leader begins at a

¹ Five species of sea turtles are endangered in at least some of their range: green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricate*), Kemp's ridley (*Lepidochelys kempii*), leatherback (*Dermochelys coriacea*) and olive ridley (*Lepidochelys olivacea*). The loggerhead turtle (*Caretta caretta*) is classified as threatened.

² Office of Protected Resources, National Marine Fisheries Service, NOAA, U.S. Dep. Commer., Silver Spring, Md. (<http://www.nmfs.noaa.gov/pr/species/turtles>).

³ NMFS is responsible for marine activities, while the U.S. Fish and Wildlife Service (FWS) is responsible for shore-based activities such as protection of beach nesting sites.

⁴ Closures to protect sea turtles have included seasonal areas closed to large mesh gillnets in the Mid-Atlantic EEZ (71 FR 24776), to the California/Oregon thresher shark/swordfish drift gillnet fishery under certain conditions (68 FR 69962) and long line gear in the Pacific Ocean (69 FR 11540).

distance greater than 3 horizontal meters (10-ft) from the mean low water line the pound net is designated as offshore, while a near-shore pound net has a leader set closer to the mean low water line (69 FR 24997).

The Virginia pound net fishery underwent a large decline during the 1980s in terms of licenses (Figure 2A), landings, and revenues (Figure 2B). In 1997, the pound net fishery in Virginia's part of Chesapeake Bay became a limited access fishery, and the number of licenses stabilized⁵. In Virginia, the pound net fishery contributes about 3% of total seafood landings (Figure 3A), and about 2% of the nominal seafood revenues (Figure 3B)⁶. The majority of pound net landings (Figure 4A) and revenues (Figure 4B) come from the part of Chesapeake Bay regulated for turtle bycatch. The regulated area includes all Virginia waters excluding the upper reaches of associated rivers (Figure 5); NMFS designated these areas as Pound Net Regulated Areas I and II (71 FR 36024)⁷.

Pound Net Regulations to Protect Sea Turtles

NMFS regulation of the pound net fishery was in response to several factors, including sea turtle strandings and observed entanglements. Since its inception over 25 years ago, the Sea Turtle Stranding and Salvage Network (STSSN) has documented sea turtles strandings on Virginia beaches, particularly in the spring when sea turtles migrate into Chesapeake Bay. In the early 1980s sea turtles were observed entangled in pound net gear, and research indicated that open-water pound nets with large mesh leaders (>25.4 cm or 10 in) or stringers had higher interactions than other leaders (Bellmund and others, 1987)⁸. In the spring of 2001, a NMFS observer found three loggerhead turtles against two large mesh leaders (about 33 cm or 13 in). NMFS implemented an emergency rule for the Virginia part of Chesapeake Bay in which, between 19 June to 19 July 2001, all pound net leaders with mesh 20.3 cm (8 in) or greater or using stringers had to be tied up (66 FR 33489) or removed. Other regulations followed, culminating in a 2006 rule that required a modified leader for offshore pound net leaders in a portion of the lower Chesapeake Bay.

To minimize future entanglements, a 2002 rule prohibited leaders with mesh 30.5 cm (12 in) or greater and leaders with stringers between 8 May and 30 June of each year in the Virginia part of Chesapeake Bay (67 FR 41196). To acquire detailed information on turtle-pound net interactions, NMFS initiated an alternative platform observer program in 2002. NMFS observers visually inspected pound nets from the surface for turtle interactions; observer trips were independent of fishing activity. The 2002 rule remained in place in 2003, but on 16 July an emergency rule prohibited the use of all pound net leaders in the Virginia Chesapeake Bay until

⁵ Virginia Marine Resources Commission. 1997. Regulation: Limits the sale of pound net licenses. (<http://www.mrc.virginia.gov/regulations/fr600.shtm>).

⁶ The phrase "nominal fishing revenue" refers to money received by fishermen at the dock for their catch, which not adjusted for inflation.

⁷ The phrase "Pound Net Regulated Area" was not used until 2006 (71 FR 36024), but the areas defined were the same as those used in 2004. Regulated Area I includes Virginia waters of the Chesapeake Bay south of lat. 37°19.0'N and west of long. 76°13.0'W and all waters south of lat. 37°13.0'N to the Chesapeake Bay Bridge Tunnel at the mouth of the Chesapeake Bay and the James and York Rivers downstream of the first bridge in each tributary.

⁸ The term stringers refer to lines that extend from the top rope of the leader to mesh lower in the water column. Stringers are generally narrowly spaced and are composed of thin twine. They are used in areas with strong tidal currents to reduce fouling of the mesh which may cause the nets to be swept away (Bellmund et al. 1987).

30 July 2003 (68 FR 41942). The emergency rule came after NMFS observers documented sea turtles in pound net leaders with mesh less than 12 inches (30.5 cm)⁹.

A new rule in 2004 (69 FR 24997) refined the existing regulations and focused on the area and conditions most likely to result in turtle and pound net leader interactions, based on observer records¹⁰. The rule required all pound net leaders in the Virginia part of Chesapeake Bay to have mesh less than 30.5 cm (12 in) and not use stringers, as in earlier rules. The regulated period was extended to 6 May and 15 July each year, and offshore pound net leaders were prohibited in Regulated Area I during this period.

During development of the 2004 rule, in the fall of 2003, representation from the NMFS, the Virginia Marine Resources Commission (VMRC), the pound net industry and other organizations and agencies met to discuss means to reduce turtle/pound net interactions. Beginning in the spring of 2004, NMFS initiated gear research with industry participants and the results of the research were used in the 2006 rule (71 FR 36024), which allowed fishermen to fish offshore pound nets in Regulated Area I during the regulated period (6 May – 15 July), if they used a modified leader. Additionally, fishermen were allowed to use modified leaders for all other pound nets, or they could continue to use leaders with mesh less than 30.5 cm (12 in) and no stringers during 6 May – 15 July each year.

Gear Research to Protect Turtles

Fishing gear modifications to reduce sea turtle bycatch have focused primarily on mobile gears. Turtle Excluder Devices (TEDs) were developed for the Gulf of Mexico shrimp trawl fishery in the 1980s and were later modified for use in other fisheries (50 CFR 223). Chain mats were designed to exclude turtles from scallop dredges used in the US Atlantic south of 41° 9.0' N. latitude (71 FR 50361). Circle hooks are mandated for the Atlantic longline fishery to reduce the incidence and lethality of turtle takes (69 FR 40734). Much of the research has involved joint work between the fishing industry and researchers; even the highly contentious introduction of TEDs in the Gulf of Mexico began with industry involved in the gear research process (Margavio and others, 1993). Thus, cooperative gear research does not guarantee a popular or quickly adopted outcome, but it may be able to protect sea turtles while taking into account a broader array of information including fishermen's concerns about harvest impacts, costs, safety, and ease of use.

Within NMFS, four of the six science centers conduct gear research to reduce the bycatch of sea turtles, including the Northeast Fisheries Science Center (NEFSC), which led the pound net research. The NEFSC has proposed a protocol for cooperative gear research to reduce protected species bycatch¹¹. The proposed process involves seven stages of gear development, design, and testing prior to the provision of information for consideration in the development of regulations (Figure 6). The premise of the process is that with groups working together they share more information; this should result in a design more likely to be successful at reducing protected species bycatch and retaining target catch. The process has the potential to allow gear researchers to identify potential problems associated with implementation in a commercial

⁹ From 21 April to 11 June 2003, observers found 12 sea turtles held against or impinged on pound net leaders by the current and five sea turtles entangled in leaders (68 FR 41942).

¹⁰ In 2002 and 2003, NMFS observers' recorded 22 sea turtles entangled or impinged in 480 offshore sampling trips and 1 turtle entangled or impinged in 345 near-shore pound net sampling trips (69 FR 24997).

¹¹ http://www.nefsc.noaa.gov/read/protsp/PR_gear_research

fishery. In addition, presumably, industry is more likely to accept and comply with bycatch reduction measures developed while they are a part of the process.

The level of involvement by groups varies within the seven stages of the proposed gear research and development process; the three groups are researchers (NMFS/NEFSC), the fishing industry, and managers (NMFS/NERO). The first stage of the process is problem identification, and involves all three groups; researchers may include gear research specialists as well as biologists and other scientists. Stage 2 is the analysis of the bycatch problem, which primarily researchers complete by drawing on data from a number of sources. Stages 3 through 6 are highly collaborative in nature, and involve the industry and NMFS. During testing stages, 4-6, if the team identifies limitations to the design they may return to stage 3, gear design. The intent of iterative process of design and testing is to maximum the reduction in bycatch, while simultaneously minimizing impact on target species harvest. Other concerns, such as cost, ease of implementation, and safety may be considered.

During the testing stages, the goal is to develop experimental designs that allow for statistical tests for differences in target catch and protected species bycatch between gears and strata¹². In stage 6, the experimental fishery, NMFS observers collect quantitative data on the use of the modified gear under commercial conditions. Observers collect data on how the gear is used, protected species interactions, and harvest. In stage 7, researchers review and summarize the work from the previous six stages. The team provides the information to NERO, which uses the information in the development of NMFS management decisions regarding protected species. As regulations are developed, NMFS researchers may be involved which allows for improved transfer of research results to regulation.

In the pound net fishery, gear research for sea turtle protection followed much of the process described above. The joint meeting in the fall of 2003 between industry, NMFS, and others was part of the process of identification (stage 1), and began the research and development that continued through 2004 and 2005. In the analysis of the bycatch problem (stage 2), observer data indicated that sea turtles had been impinged and entangled in the upper portion of the mesh of pound net leaders. However, as observations were made from the water surface and poor water clarity limited the depth of observations, interactions with lower parts of the mesh were possible. This information, along with input from fishermen was used during gear design (stage 3). The first version of the modified leader was field tested in 2004 (stage 4). Four pound nets, owned and operated by two fishermen, were used to compare turtle interactions with the control leader and the modified leader (DeAlteris and others, 2005)¹³. During testing, one leatherback turtle was entangled in an experimental leader, compared to six hard-shell turtles in the control leaders. Statistical comparisons were not possible due to limited numbers of observations, in terms of days and interactions.

Based on the 2004 results, the team returned to stage 3 (gear design) and further modified the leader. In 2005, researchers tested the second (and final) version of the leader using the same four pound nets (stage 4). Testing looked at both turtle interactions and the volume and size of fish harvested in the control leader and the modified leader (DeAlteris et al., 2005). Leaders were inspected twice daily from the surface (visual) and with side-scan sonar to identify turtle

¹² A fishery can be divided into groups, or strata, based on a number of features. For example where the gear is used may include different local physical features (e.g. currents, depth), and differences in fishing techniques by target species may have an impact on the effectiveness of a gear modification.

¹³ The control leader was similar to that regulated for use by near-shore pound nets in Regulated Area I and all pound nets in Regulated Area II.

interactions¹⁴. All 15 observed turtle interactions occurred in the control leaders; the controls were removed after 30 days (of a 55-day study period) due to the high interaction rates. Examination of the catch from the pounds with modified and control leaders indicated there were no statistically significant differences in harvest rates and size of fish between the gears (DeAlteris et al., 2005).

In the strict sense, testing of the modified leader under commercial conditions (stage 5) and in an experimental fishery (stage 6) did not occur due to closure of the affected fishery. Testing conducted in 2004 and 2005 was under quasi-commercial conditions (stage 5). Fishermen may have altered their harvesting schedule as part of the research project; however, the research impacts on commercial fishing practices were limited. One could also argue that because testing involved about half of the affected pound nets, about one-third of the affected fishermen, and the level of “observer” coverage was very high, the 2005 data may have provided similar, or better, data than an experimental fishery.

Following 2½ years of gear research, development, and testing, researchers concluded that the final modified pound net leader design provided a high level of protection to sea turtles, a level that was statistically indistinguishable from removal of the gear. NERO used this information in the development of the 2006 regulations. The level of adoption of the modified leader is unknown; however, there appeared to be enthusiasm among the fishermen involved in the experimental trials.

METHODS

A cost-effectiveness framework was used to compare the two alternative actions, a closure and gear research. Cost-effectiveness compares costs per unit of outcome, which can be measured in physical units (e.g. per turtle saved)¹⁵. In this case study, quantifiable outcomes were not available either in terms of number of turtles saved or impacts on turtle populations¹⁶. However, results showed that the gear modification and closure provided a level of protection that was statistically indistinguishable, and so the costs are directly compared, as the outcomes between two alternatives are equal.

Data

We used trip level data from the Virginia Marine Resources Commission (VMRC) to calculate the average landings and revenues per pound net by fishing location and time. We calculated the average landings, by species, per pound net using the average number of pounds fished per trip times the number of fishermen. Data used was for 6 May to 15 July from water bodies partially or wholly in Regulated Area I. An average for 1998-2000 was calculated, to reduce the impact of the intermittent closures that occurred between 2001 and 2004. Value was calculated using the average species price from 6 May to 15 July 2004, the first year described by the scenarios.

To estimate the number of offshore pound nets affected under the scenarios examined, we used data collected during 2002-2004 by the Domestic Fisheries Observer Program, Fisheries

¹⁴ Divers confirmed all positive sonar targets.

¹⁵ Alternatively, the unit of outcome could be denominated in dollars of benefit, in which case the result is a cost-benefit ratio.

¹⁶ Consequently, even if an accepted measure of public willingness-to-pay (WTP) for turtle protection existed, the quantification of benefits would not be possible.

Sampling Branch, NEFSC, NMFS, Woods Hole, Mass. There was an average of eight active offshore pound nets in Regulated Area I during 2002-2004.

We used cost data from several local harvesters fishing pound nets in the Virginia Chesapeake Bay to estimate the cost of fabrication of the modified and standard leader and removal and deployment of a leader. Fabrication costs for a leader included materials and labor. We assumed the life of a leader was 5 years, and that materials were paid over a 5-year period at 10% interest, while labor was fully paid in the first year. For the modified leader, annual payments were \$1,389 per leader, with a first year cost of \$2,198 per leader (\$1,389 materials payment + \$809 labor). For the standard leader, annual payments were \$1,662 per leader, with a first year cost of \$3,034 per leader (\$1,662 materials payment + \$1,372 labor). The cost of removal and deployment of a leader was estimated to be \$838 per leader for each action (removal or deployment).

Leader removal and deployment costs were assessed for all pound nets under the full closure scenario, and for the four pound nets covered by a partial closure during the research program. Under closure, fishermen were required to remove or tie-up their leaders at or before the regulated period (6 May) and redeploy or reset the leader at the end of the closed period (15 July), in order to fish. This set of actions would cost \$1,676 per leader (removal plus deployment). For pound nets involved in the gear research program, fishermen were paid to change the leader between the control and modified leader, thus this is included in the research costs and not assessed separately.

Anecdotal reports suggested that pound net fishermen in the south-east Chesapeake Bay might use the modified leader during the entire fishing season, rather than just during the regulated period (6 May – 15 July). The modified leader has physical characteristics that may allow fishermen to leave the leader in the water longer and may decrease the amount of damage to the leader mesh from contact and fouling from objects in the water. Offshore pound nets in the lower Bay tend to be located in deeper water in areas of relatively strong currents. Historically, their leaders have been made with large mesh or stringers (Bellmund et al., 1987), to minimize fouling and the potential for leader damage. Consequently, we assumed that with the modified leader, fishermen did not need to remove the leader beyond that necessary for regular maintenance or at the beginning and end of the season and costs for removal and deployment are not assessed.

As an estimate of research costs, we used the direct gear research costs paid by NMFS¹⁷. The research was conducted in cooperation with fishermen, but with Federal government funding. There was no direct cost to the fishermen; however, there was an opportunity cost for the funds¹⁸. The opportunity cost was valued as the direct costs of the research program and did not include the cost of NMFS employees' time or travel (Table 1); this created a downward bias in the cost estimate.

The fishermen whose nets were used in the trials were not compensated for the use of their pounds; however, they were able to fish and sell their catch during the period of the experiment when they otherwise would not have been able to do so. In an open commercial fishery, a gear research program may pay a fee to fishermen for use of their equipment (e.g.

¹⁷ A reviewer noted that the research costs do not include the cost of an observer program. Based on the assumption an observer program would be appropriate under either scenario, observer costs are not included.

¹⁸ Opportunity cost refers to the value of the funds in their next best use. The opportunity cost may be higher than the monetary value; however, using the dollar value provides a lower bound for opportunity cost in a budget constrained system.

vessel, pound, etc.) and for any inconvenience due to research activities. Such a payment would be considered part of the cost of research. However, in a fishery closed due to regulation such as the pound net fishery, allowing fishermen to keep and sell any harvest collected during the research program may be an alternative. This would still be considered a cost of research.

Cost Calculations

Costs for fisheries management actions that protect sea turtles are composed of losses to consumer and producer surpluses¹⁹. In the case of a closure, there is potential for a loss in consumer surplus for seafood products if prices increase due to reduced supply. However, the pound net fishery supplied only a small part of Virginia's overall seafood harvest (Figure 3), the number of affected pound nets was small, and the duration of the closure short. With a global seafood market, a local reduction in supply is unlikely to have a substantial effect on consumer surplus; we assumed there was no impact.

Both a closure and gear modification alternative could have a negative impact on producer surplus. We assumed Virginia Chesapeake Bay pound net fishermen were unable to influence the price they receive for their fish, so profit was given by,

$$\Pi_i = TR_i - TVC_i - FC_i \text{ with}$$

$$i=B, C, G$$

where Π is profit, TR is total revenue, TVC is total variable cost, FC is fixed cost and i is the management action (B = before action, C = closure and G = gear modification)²⁰. Of interest were values during the management action (6 May – 15 July). The cost of a management action is the difference in profits without the action (B) and with the action (C or G).

During the closure, we assumed fishermen did not fish their pounds when the leaders were removed, thus revenues and variable costs were zero when leaders were tied up or removed. Removal and redeployment of the leader increased fixed costs. The cost of the closure was,

$$\Pi_B - \Pi_C = (TR_B - TVC_B - FC_B) - (TR_C - TVC_C - FC_C)$$

with $TR_C=0$ and $TVC_C=0$ so that,

$$\Pi_B - \Pi_C = (TR_B - TVC_B) + (FC_C - FC_B).$$

The annual cost of the closure was the difference between total revenues and total variable costs before the closure, plus any increase in fixed costs due to the closure²¹. Without reliable

¹⁹ Consumer surplus is the difference between the market price a consumer must pay for a product and what they would be willing to pay for it. Producer surplus, or economic profit, is the difference between the revenue generated from sales of a product and the full cost of production, including variable and fixed costs.

²⁰ Variable costs are costs that vary with the level of fishing effort (production), often referred to as trip costs. Fixed costs do not vary directly with the level of fishing effort; for our purposes, we include the costs of removal and redeployment of leaders as well as the annual ownership costs of the leader.

²¹ This study assumes that the loss in net revenues by fishermen represents the loss in producer surplus from a closure. If fishermen are able to shift to another fishery or alternate locations and maintain their net revenues, then this assumption overstates the social cost of a closure. The pound net fishery is a fixed gear with limited entry and limited mobility in pound location. While pound net gear provides the majority of affected fishermen revenues,

information on variable trip costs for pound net fishermen, a range of variable cost values as a percentage of total revenues (0-50%) were used to test the sensitivity of the results to alternative assumptions²².

In the case of the gear modification, we assumed a closure was in effect during the 2 years of gear development. After the modified leader was implemented, we assumed harvest levels returned to those prior to the closure. Additionally it was assumed that the variable cost of operating the modified gear was the same as that for the standard gear. What would change is the fixed ownership cost associated with the new leader requirements. Thus, the change in producer surplus in the years after implementation of the modified gear was,

$$\Pi_B - \Pi_G = (TR_B - TVC_B - FC_B) - (TR_G - TVC_G - FC_G)$$

with $TR_G = TR_B$ and $TVC_G = TVC_B$ so

$$\Pi_B - \Pi_G = (FC_G - FC_B)$$

which is the difference in the fixed, or annual, cost of the modified and standard leader. Fixed cost differences were calculated for 5 pound nets for the first 5 years and for all 8 pound nets in subsequent years. As part of the gear research project, participating fishermen were allowed to retain the three experimental leaders fabricated. It was assumed that all leaders would be replaced at the same time²³.

To equate the outcomes of the two scenarios in terms of benefits to turtle populations, a slight modification to the cost model was required. Under the gear research scenario, turtle takes occurred during both years of the research. The experimental design called for use of the control leaders approximately half of the time for each pound net site. Thus, approximately 2 pound nets worth of fishing time was with control leaders. Under a closure, one would assume that there were no turtle takes, as the leaders would not be in the water. To deal with this difference, for the first 2 years of the scenarios only 6 of the 8 pound nets were closed²⁴. In years 3 and later, all 8 pound nets are closed under the closure scenario to ensure turtle outcomes are similar to those with the modified leader. To compare costs over future years, the costs were discounted with a range of values (4-7%)(Office of Management and Budget, 1994), as a way to test the sensitivity of the results under alternative assumptions.

RESULTS

these fishermen also use gillnet, pot, and other gear. We did not examine the potential for such shifts, although shifts to other gear types could offset benefits to turtle populations provided by a closure.

²² There are no data on variable costs for the pound net fishery. In the absence of such data, estimates have been done without variable costs (VC=0%). However, this can result in a significant overestimate of costs if the fishery has high variable costs. In the absence of information on variable trip costs, a range of values is presented to illustrate the impact of alternative cost scenarios.

²³ Fishermen participating in experimental gear research may retain the gear, although this is not universal. In this case, the research program paid for materials and labor to fabricate the leaders so including the cost for all eight leaders would have resulted in double counting of costs.

²⁴ This is not a preferred method to deal with this difference in turtle takes, but in the absence of quantitative data on turtle take rates or total bycatch it may be appropriate. One could think of the initial exclusion and then inclusion of the two pound nets as a redefinition of closure boundaries due to better information.

Mean landings per pound net in the lower Bay between 1998 and 2000 for the 6 May to 15 July period was 26,289 kg (CV=22%), for a revenue estimate was \$26,020 per pound net (CV=23%) (Table 2).

For each alternative, five scenarios for variable fishing costs, as a percent of revenues (VC=0-50%), are presented as well as four levels of discount rate for the determination of present value (4-7%).

With the closure, the annual (nominal) cost for the first 2 years, when only six of eight pound nets are closed, ranges between \$166,176 (CV=22%) when variable costs are not included to \$88,116 (CV=21%) when variable costs are 50% of revenues (Table 3). In years 3-10, when all eight pound nets are closed, the cost does not change and ranges from \$221,568 (VC=0%) to \$117,488 (VC=50%). The CV decreases slightly as variable costs increase. All the variation is in the estimate of revenue, so with higher variable cost, the non-varying fixed cost for removal and redeployment of leaders accounts for a larger share of the total costs.

The annual cost for gear modification is highest during the first 2 years and then becomes negative (i.e. cost saving) in year 3 (2006) onward (Table 3). A partial closure is in effect during the 2 years of gear research, thus, total annual costs are lower when variable cost is higher. As with the closure, the only source of variation is in the revenue estimate; thus, after adoption of the modified leader there is not variation in the estimates. In the third and subsequent years, when fishermen are allowed to use the modified leader, cost is negative indicating a cost saving as the modified leader has a lower ownership cost than the standard leader. We assume replacement of leaders every 5 years, so there are greater cost savings in replacement years (e.g. 2006 and 2011).

The present value of costs for the two actions over a 10-year time horizon differs with the discount rate (Table 4), but in all cases, the cost of the gear modification is lower than that of the closure. A higher variable cost reduces the cost of the closure, and a higher discount rate makes gear research more costly due to the higher up-front costs. The cumulative present values of cost for the two actions follow different trajectories (Figure 7). When variable costs are not considered (i.e. 0% of revenues; Figure 7A), the cumulative present value of costs for the closure exceed that of gear modification at around year 4. However, when variable costs are a high proportion of revenues (i.e. 50%; Figure 7B), the cumulative present value of cost of the closure exceeds that of gear modification around year 6²⁵.

DISCUSSION

Protected species bycatch is a product of the amount of effort and the bycatch rate per unit of effort (Hall and others, 2000). To reduce total bycatch, reductions in effort and/or the bycatch rate are required. Time and/or area closures can reduce effort, while gear modifications reduce the bycatch rate. In the pound net fishery in the Virginia Chesapeake Bay, observer data helped to identify an area with a potentially high bycatch rate, the offshore pound nets in the lower Bay. In 2004, these pound nets were subject to a seasonal closure (6 May – 15 July) to reduce effort. In 2006, the modified leader requirement replaced the closure, in essence to reducing the bycatch rate²⁶. Sea turtle protection with the modified gear is expected to be similar to that under the seasonal closure. The lower present value of costs from gear research illustrate

²⁵ This holds for all discount rates illustrated in Table 4.

²⁶ A bycatch rate for sea turtles in the pound net fishery was not calculated. However, the experimental design for the modified gear research in effect modeled a difference in bycatch rate between the control and modified leaders.

that it is cost-effective relative to the closure (Table 4). The cost savings under the gear research scenario over the closure scenario can be a benefit from gear research.

Seasonal closures to specific gears have been used to reduce bycatch of several protected species in commercial fisheries, including harbor porpoise, the North Atlantic right whale, and sea turtles^{27,28,29}. For a small fishery, the costs to society of a closure may be low and costs will be even lower if only a portion of the fishery is affected. The pound net fishery accounts for only a small portion of total seafood landings in Virginia (Figure 3) and the scenarios only affected eight of 58 active pounds. While the social cost may be low, the cost to individual fishermen may be high. It was estimated that the cost of the closure was borne by five fishermen (National Marine Fisheries Service (NMFS), 2006). Between 1998 and 2004, the closure period (6 May-15 July) accounted for 43-53% of annual pound net revenues for fishermen in the lower Bay³⁰.

Gear modifications may reduce protected species bycatch at a lower cost than closures; in this example, the cumulative present value of cost for the gear modification is lower than that for a closure after 4-6 years (Figure 6). The transferability of these results to other fisheries, gears or protected species will depend on factors that influence the length of the research period or probability of success, factors that affect direct annual research costs, and the scale of the fishery in terms of net revenues.

Gear research for the pound net fishery provided a useful modification in two years. A two-year development and testing period may be short, and this speed of success may be hard to replicate. Lengthening of the amount of research time necessary for a successful outcome would increase the total direct costs, as well as the indirect cost of the associated closure.³¹ In the pound net example, four factors appear to have increased the probability of success for the gear research.

First, there was a large body of information and data available on the fishery and its interaction with sea turtles. Research in the Chesapeake Bay on sea turtles and turtle-gear interactions has been on-going for several decades (Bellmund et al., 1987; Lutcavage, 1981; Mansfield and others, 2001). Additionally, researchers had several years of observer data (2002-2004) on the pound net fishery during the peak interaction period (May-June). The observers made frequent observations of the commercial pound nets, examining some nets two times in a day. Protected species interactions with fishing gear tend to be rare events and high levels of

²⁷ The Harbor Porpoise Take Reduction Plan (63 FR 66464) defined a series of timed gillnet closure areas in the Gulf of Maine, south of Rhodes Island/Massachusetts, off New Jersey, and along the Atlantic coast down to North Carolina.

²⁸ In an effort to protect the North Atlantic right whale (NARW), the Atlantic Large Whale Take Reduction Plan (50 CFR 229.32) provides for seasonal closures of the Cape Cod Bay Restricted Area and the Great South Channel Lobster Restricted Area to anchored gillnet and/or lobster trap gear and dynamic area management (DAM) restrictions where concentrations of whales are located. Additionally, emergency or temporary closures have been implemented (e.g. 71 FR 8223) when NARW mortality has been directly linked to a specific gear type in a Restricted Area.

²⁹ Closures to protect sea turtles have included seasonal areas closed to gillnets with mesh greater than 8-inches in the Mid Atlantic EEZ (67 FR 71895), closure of the California/Oregon thresher shark/swordfish drift gillnet fishery for June, July, and August in El Niño years (68 FR 69962), and area closures to various longline gear in the Pacific Ocean (69 FR 11540).

³⁰ NMFS. 2006. Final Environmental Assessment and Regulatory Impact Review Regulatory Flexibility Analysis of Sea Turtle Conservation Measures for the Pound Net Fishery in Virginia Waters of the Chesapeake Bay. June. Available at http://www.nero.noaa.gov/prot_res/seaturtles/regs.html

³¹ In this example, partial closure of the fishery occurred during the research period, which allowed for equal benefits from turtle protection from the two actions, as discussed in the Methods section.

observer coverage can increase the data incorporated in a gear research program, presumably increasing the likelihood of success for gear research.

Second, the physical nature of the pound net fishery was a factor. Pound nets are located close to shore in relatively shallow water and are a fixed gear; this allows for frequent observation at known locations. In addition, multiple observation platforms were possible, in this case surface visual inspection, side-scan sonar, and divers.

Third, the affected pound net fishery was small and the affected gear homogeneous. This decreased the number of strata in which the gear had to be tested³². If fishermen will use the modified gear in different areas, during different seasons and/or with different base gear, the number of tests and observations required will increase.

Finally, the degree of cooperation by fishermen enhanced the probability of success for the gear research. The gear researchers worked closely with participating pound net fishermen. Prior to the design of the modified leader, the research team consulted fishermen regarding aspects of the gear they felt influenced seafood harvest and turtle interactions. This, along with previous research, provided sufficient information to design a gear that was successful after minor modification.

These four factors can also influence the direct annual research costs associated with gear research. First, if information on a fishery and its interaction with a protected species is limited, then additional funds will need to be needed for basic research. Second, when a fishery is located far from shore and/or in deep waters (e.g. bottom trawls, scallop dredge) costs increase. As well, the equipment required to monitor such fisheries may be costly or not available, requiring development costs. Third, with a heterogeneous fishery, the number of trials and observations may require more equipment, a more complex experimental design and/or more researchers. Finally, a lack of cooperation by fishermen can increase direct costs by requiring payment to undertake trials. Even when there is good cooperation, payment to fishermen to offset losses in revenues may be necessary to allow the implementation of an appropriate experimental design.

A larger fishery with higher net revenues would have a much higher cost associated with a closure. If research costs were similar to those for the pound net fishery, benefits from gear research would be realized much sooner, even in the presence of a partial closure during research. The results, however, show that even for a very small fishery, benefits from gear research may be possible in a short time.

In this example, a large part of the cost of gear research was attributable to closure of the affected fishery while research and testing was underway. This upfront cost increased the time until there was an economic return on the research investment; that is, to the point where the cumulative present value of cost was equal between the two actions (Figure 7). In the absence of an associated closure, the gear research action would have provided a return in 0-4 years, depending on the variable cost assumption. Had research required 3 years rather than 2, with a closure, the time required for a return on the research investment would have extended to 6-10 years; the economic benefit from the gear research compared to a closure would be zero or small over 10 years. Thus, initiating research before a closure is required would increase the economic benefits from research. When a species is in grave peril, forestalling a closure may not be prudent; however, from an economic perspective it may be appropriate when a fishery is responsible for only a small number of takes relative to total mortality³³. A possible course of

³² If there are concerns about possible heterogeneity within a fishery, it may be appropriate to have an experimental fishery with a high level of observer coverage.

³³ Public benefits (i.e. consumer surplus) for protected species are measured based on changes. If a regulation has a

action is a program that initiates gear research in the absence of a closure with a target completion date, at which point either a successful gear modification is implemented or a closure is enacted.

Gear research is expensive³⁴. The cost for this example was \$367,175 over 2 years (Table 1), which appears to be similar to other gear research projects. For example, the Northeast Consortium has provided funds for cooperative gear research since 2000, with a focus on reduction of fish bycatch³⁵. Of the 60 gear-related projects funded to 2006, 34 cooperative projects were awarded between \$50,000 and \$262,524 in grants and took 1-4 years to complete; additionally, funding from other sources may have been used³⁶. Of note is that the designs of most research projects require additional experimental tests in order to use the results in a regulatory setting.

Given the cost of gear research, external funding can be very important for a small fishery such as the pound net fishery; however, proactive private investment by fishermen may be an option. Several regulated fisheries have implemented “research set-aside” (RSA) programs that may reserve part of the harvest quota and/or days-at-sea to fund research activities; for a large fishery, this can result in significant funds for research³⁷. For example, the Atlantic sea scallop fishery sets aside 2% of total allowable days-at-sea (DAS) and shares of the total allowable catch (TAC) in several access areas. For the 2007 year, the estimated value of the DAS RSA was \$4.2 million, with the value for three TAC RSAs valued at \$5.7 million (71 FR 33898); the total is equal to about two percent of the Atlantic sea scallop revenues in 2005³⁸. Funds from the set aside catch are used to cover the cost of approved research projects including gear modifications, salaries of research personnel or vessel operation costs (70 FR 60790). Even for a small fishery, private investment in gear research may make financial sense. The average annual revenues for lower Chesapeake Bay pound net fishermen was \$79,503 from 2000 to 2004 (National Marine Fisheries Service (NMFS), 2006); for the five affected fishermen annual revenues were less than \$400,000 per year. Direct research costs were 40-52% of the annual value, similar to the revenue lost due to the closure. The fishermen may have had an incentive to invest in the research themselves had they not been subject to a closure; the annual payments for a 10-year loan at 10% would be \$59,756, about 15% of total annual average revenues. That is, the payments would be lower than the estimated loss in revenues from a closure.

This case study illustrates a potential additional incentive for fishermen to invest in gear research: cost savings. The fixed cost of the modified leader is less than that of the standard leader. While the savings are modest, they may encourage broader adoption of the modified

small or no measurable impact on the number of turtles saved or population survival, public benefits are likely to be small even in the presence of an accepted willingness-to-pay measure.

³⁴ A reviewer suggested that the financial outlays by the Federal government should not be counted as a cost, given that the government, as steward of the resource (e.g. sea turtles), must bear the costs of research to ensure protection. While there is a public good aspect to gear research for protected species, there is still an opportunity cost associated with conducting this research; these funds could be used in other fisheries or for other protected species. As we are considering social costs, we must consider these costs; the financial costs of the research are an imperfect measure of social cost but provide a minimum estimate.

³⁵ <http://www.northeastconsortium.org/projects.shtml>.

³⁶ L. Smith, Northeast Consortium, 39 College Road, 142 Morse Hall, Durham, NH 03824. January 30, 2007. Personal communication.

³⁷ <http://www.nero.noaa.gov/sfd/sfdrsa.html>

³⁸ The research set aside programs are valued based on 2005 prices (71 FR 33878). The 2005 revenues for sea scallops for Atlantic states (Maine to Virginia) was approximately \$432.5 million (http://www.st.nmfs.gov/st1/commercial/landings/annual_landings.html).

leader. While lower cost was not a design criterion for leader development, it does suggest that cooperative research can achieve multiple goals.

Successful gear research projects can also provide additional benefits to gear researchers, beyond immediate bycatch reduction. A comprehensive scientific gear research program can provide insight into animal behavior that may be applicable to other gear types or other bycatch problems. The pound net research shows that fish can be effectively herded using leaders with ropes spaced every 61 cm (24 in). Other research teams may wish to test this leader design in similar gears in areas with different bycatch concerns. The a-priori knowledge of the successful utilization in one fishery will alleviate the time and resources needed to develop a possible solution in another fishery.

Public awareness and concern regarding protected species bycatch continues to grow, suggesting pressure will continue to mount to find solutions. Closures to protect species such as sea turtles may provide large and immediate reductions in bycatch, but the costs to fishermen can be high and extend indefinitely. Gear modifications may provide similar reductions in bycatch, but they take time to develop and may have significant up-front costs. Society as a whole has an interest in finding cost-effective solutions to bycatch reduction; this research indicates gear modification can be cost-effective. Cooperative gear research between the fishing industry, researchers, managing agencies, and environmental organizations appears to be growing, although funding remains an on-going constraint. This example with turtles and pound nets shows how quickly a cooperative gear research program can yield benefits to society and fishermen when the alternative is a closure. Additional benefits such a cost savings for fishermen only strengthens the argument that the fishing industry has an incentive to assist in the direct funding of gear research to reduce protected species bycatch.

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Table 1. Gear research costs to develop a modified pound net leader, 2004 and 2005.

Cost category	2004	2005
Construct, modify & set leaders	\$ 38,000	\$ 24,000
Monitoring incl. side scan sonar	\$118,375	\$172,300
Miscellaneous	\$ 4,000	\$ 10,500
Total	\$160,375	\$206,800
Study days	42	55

Table 2. Average (1998-2000) landings per pound net in the lower Chesapeake Bay for May 6 – July 15, and estimated revenue per pound net using average prices for 6 May-15 July 2004.

Species	2004 price		Landings		Estimated revenues	
	Mean (\$/kg)	CV (%)	Mean (kg/net)	CV (%)	Mean (\$/net)	CV (%)
Bait fish	0.18	25	5,952	74	1,050	78
Blue Crab	1.85	80	9	173	17	191
Bluefish	0.84	29	235	74	197	79
Butterfish	1.06	31	338	18	357	36
Catfish	0.62	18	0	173	0	174
Croaker (Atlantic)	0.60	22	10,968	23	6,528	32
Flounder	3.53	20	53	72	186	75
Herring	0.73	-	-	-	-	-
Menhaden	0.29	-	57	173	16	173
Spadefish	0.88	38	189	15	167	40
Spanish Mackerel	1.70	12	999	19	1,695	22
Spot	1.30	8	191	82	249	83
Star (Harvestfish)	2.78	5	424	51	1,179	51
Sea Trout	1.65	24	6,064	48	10,027	53
Striped Bass	6.08	12	227	29	1,379	32
Shad	0.18	13	2	173	0	174
White Perch	0.93	14	-	-	-	-
Misc. Fish	5.11	47	581	14	2,972	49
Total	1.06	85	26,289	22	26,020	23

Table 3. Mean annual direct cost of closure and gear modification under alternate Variable Cost (VC) scenarios, in 2004 dollars (CV in parentheses in %).

VC	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Closure										
0	166,176 (22)	166,176 (22)	221,568 (22)	221,568 (22)	221,568 (22)	221,568 (22)	221,568 (22)	221,568 (22)	221,568 (22)	221,568 (22)
20	134,952 (21)	134,952 (21)	179,936 (21)	179,936 (21)	179,936 (21)	179,936 (21)	179,936 (21)	179,936 (21)	179,936 (21)	179,936 (21)
30	119,340 (21)	119,340 (21)	159,120 (21)	159,120 (21)	159,120 (21)	159,120 (21)	159,120 (21)	159,120 (21)	159,120 (21)	159,120 (21)
40	103,728 (21)	103,728 (21)	138,304 (21)	138,304 (21)	138,304 (21)	138,304 (21)	138,304 (21)	138,304 (21)	138,304 (21)	138,304 (21)
50	88,116 (21)	88,116 (21)	117,488 (21)	117,488 (21)	117,488 (21)	117,488 (21)	117,488 (21)	117,488 (21)	117,488 (21)	117,488 (21)
Gear modification										
0	323,199 (9)	369,624 (8)	-4,184	-1,367	-1,367	-1,367	-1,367	-6,695	-2,187	-2,187
20	291,975 (8)	338,400 (7)	-4,184	-1,367	-1,367	-1,367	-1,367	-6,695	-2,187	-2,187
30	276,363 (7)	322,788 (6)	-4,184	-1,367	-1,367	-1,367	-1,367	-6,695	-2,187	-2,187
40	260,751 (7)	307,176 (6)	-4,184	-1,367	-1,367	-1,367	-1,367	-6,695	-2,187	-2,187
50	245,139 (6)	291,564 (5)	-4,184	-1,367	-1,367	-1,367	-1,367	-6,695	-2,187	-2,187

Table 4. Present value over 10 years of closure and gear modification under alternate scenarios for variable cost (as a percent of revenues) and discount rate.

Variable Cost	Discount rate			
	4%	5%	6%	7%
Closure				
0	1,760,349	1,688,290	1,620,959	1,557,977
20	1,429,584	1,371,065	1,316,386	1,265,238
30	1,264,202	1,212,453	1,164,099	1,118,868
40	1,098,820	1,053,840	1,011,812	972,498
50	933,437	895,228	859,525	826,128
Gear Modification				
0	661,928	659,382	656,842	654,312
20	600,681	598,421	596,162	593,906
30	570,058	567,940	565,821	563,703
40	539,434	537,460	535,481	533,501
50	508,810	506,979	505,140	503,298
Difference				
0	1,098,420	1,028,908	964,117	903,666
20	828,903	772,644	720,224	671,332
30	694,144	644,512	598,278	555,165
40	559,386	516,381	476,331	438,997
50	424,627	388,249	354,385	322,830

Figure 1. Stationary uncovered pound net with pound, heart and leader. Source: Food and Agriculture Organization. [<http://www.fao.org/fishery/geartype/246>].

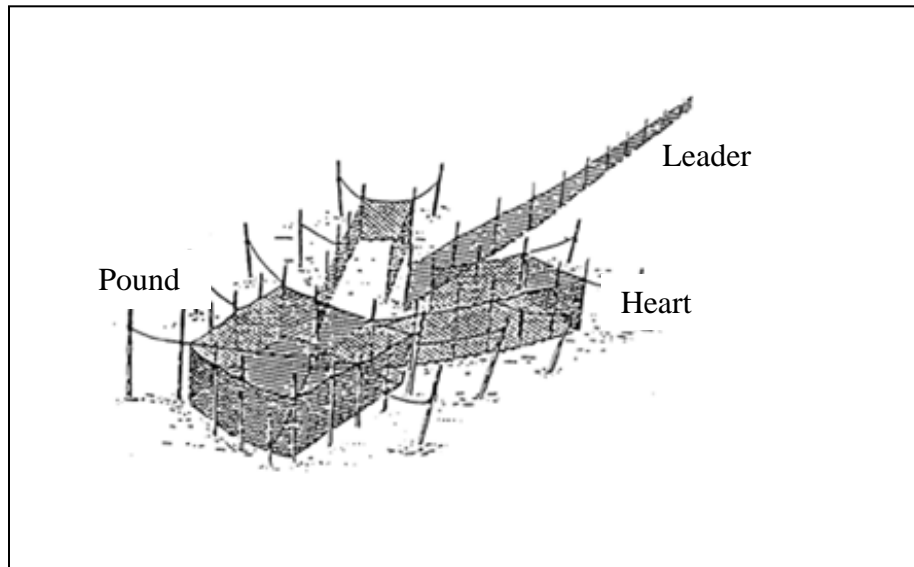


Figure 2. Changes in the Virginia pound net fishery 1980 – 2004: (A) number of pound net licenses sold in Virginia and (B) pound net landings and nominal revenue for Virginia.

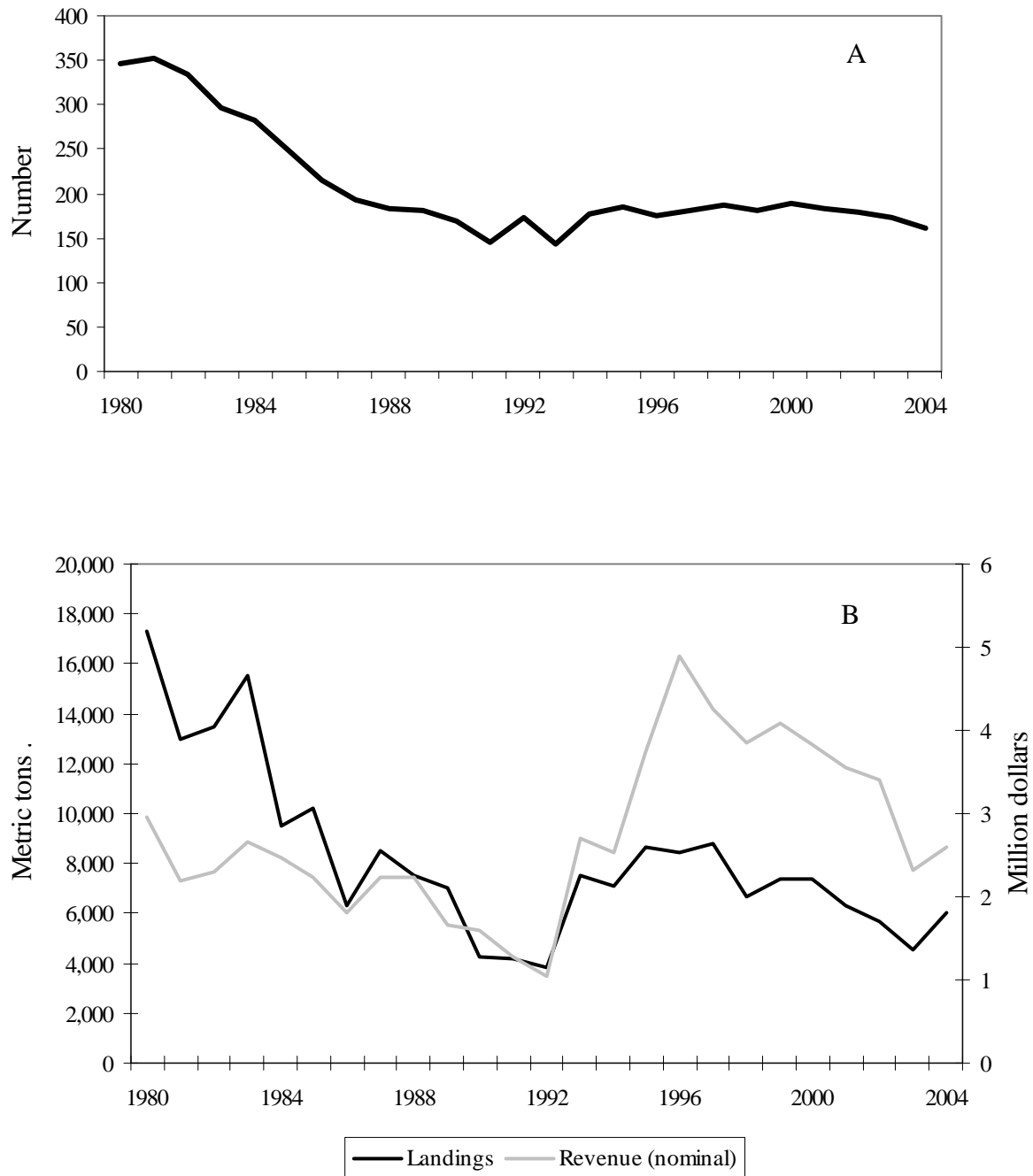


Figure 3. Virginia total fisheries: (A) landings and (B) revenues (nominal) and the share accounted for by the pound net fishery, 1980-2004.

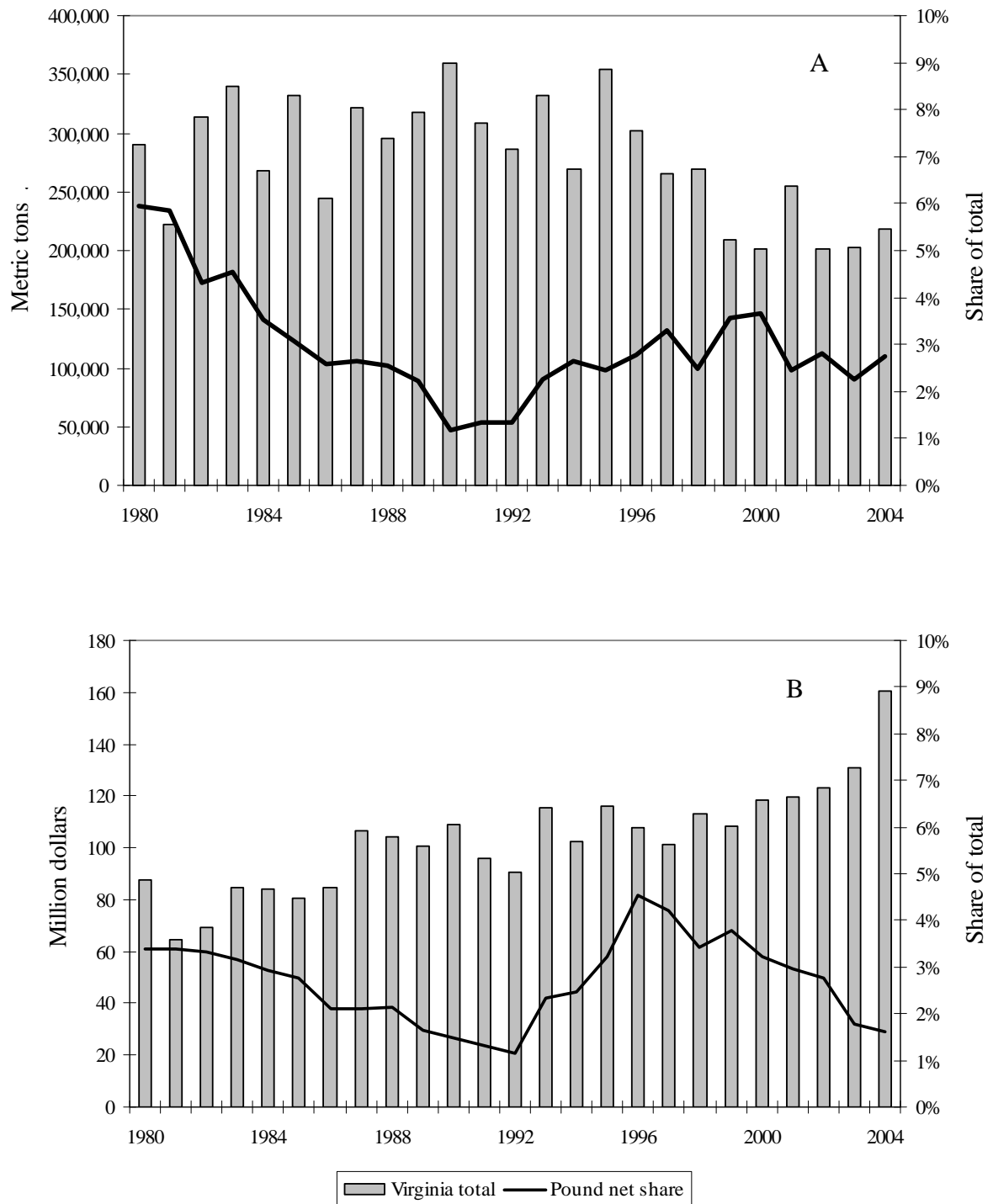


Figure 4. Distribution of pound net fishery: A) landings and B) revenues (nominal) between Virginia Chesapeake Bay area regulated for sea turtles (light) and that not regulated for sea turtles (dark).

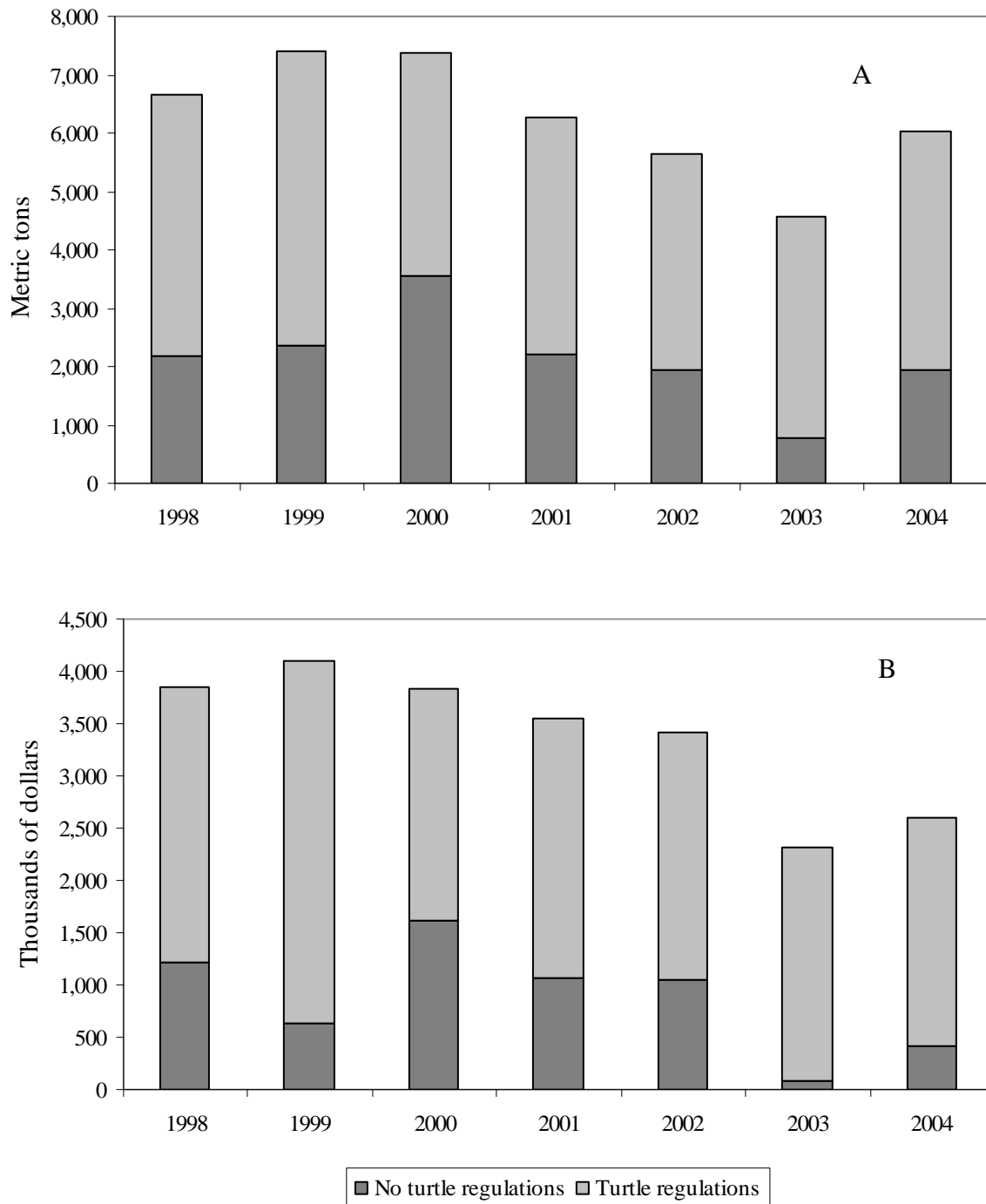


Figure 5. Portion of Virginia Chesapeake Bay regulated to protect sea turtles, designated Pound Net Regulated Area I and II (dashed and hatched).

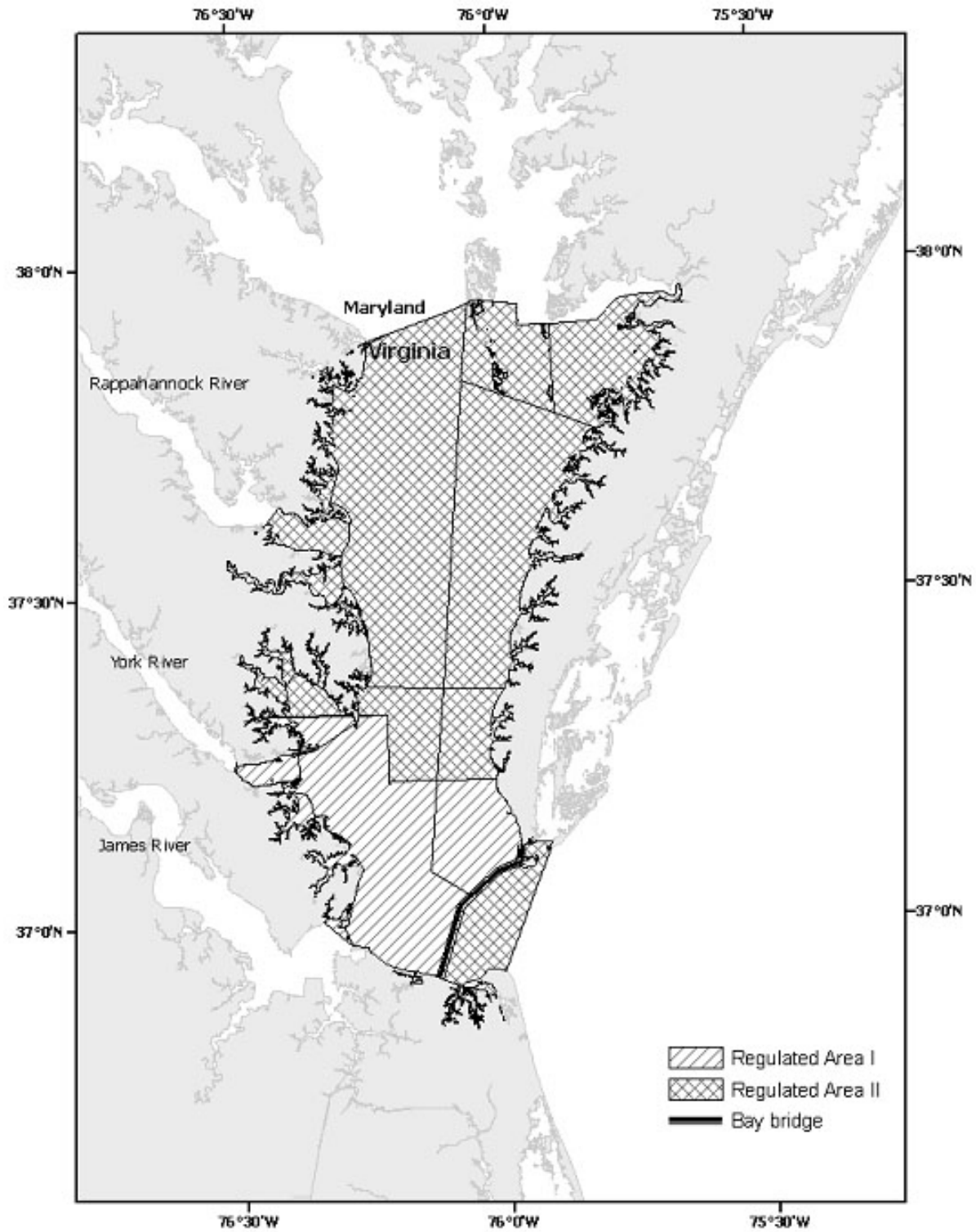


Figure 6. Flow chart of cooperative gear research process to reduce bycatch of sea turtles, proposed by National Marine Fisheries Service (NMFS).

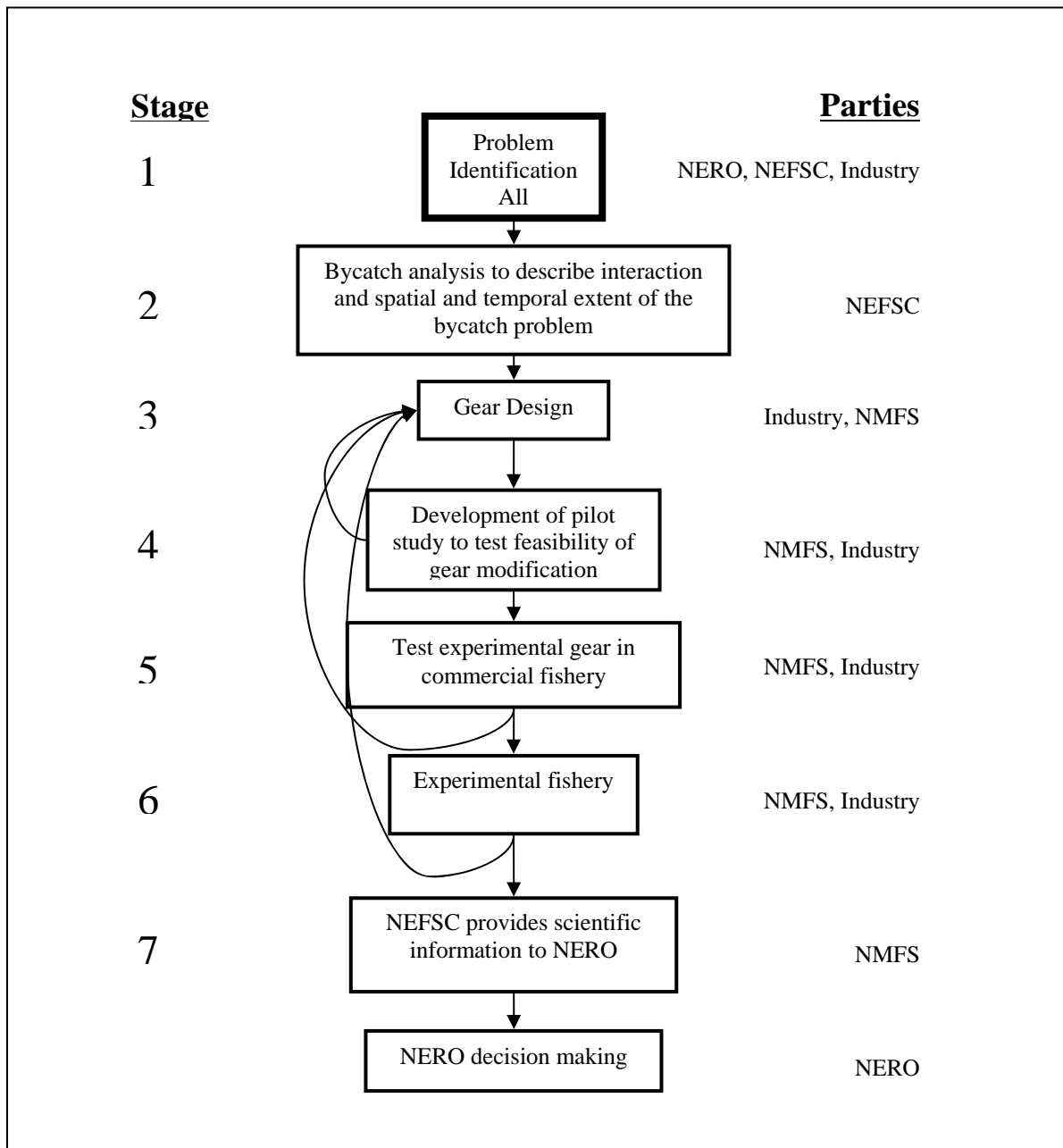
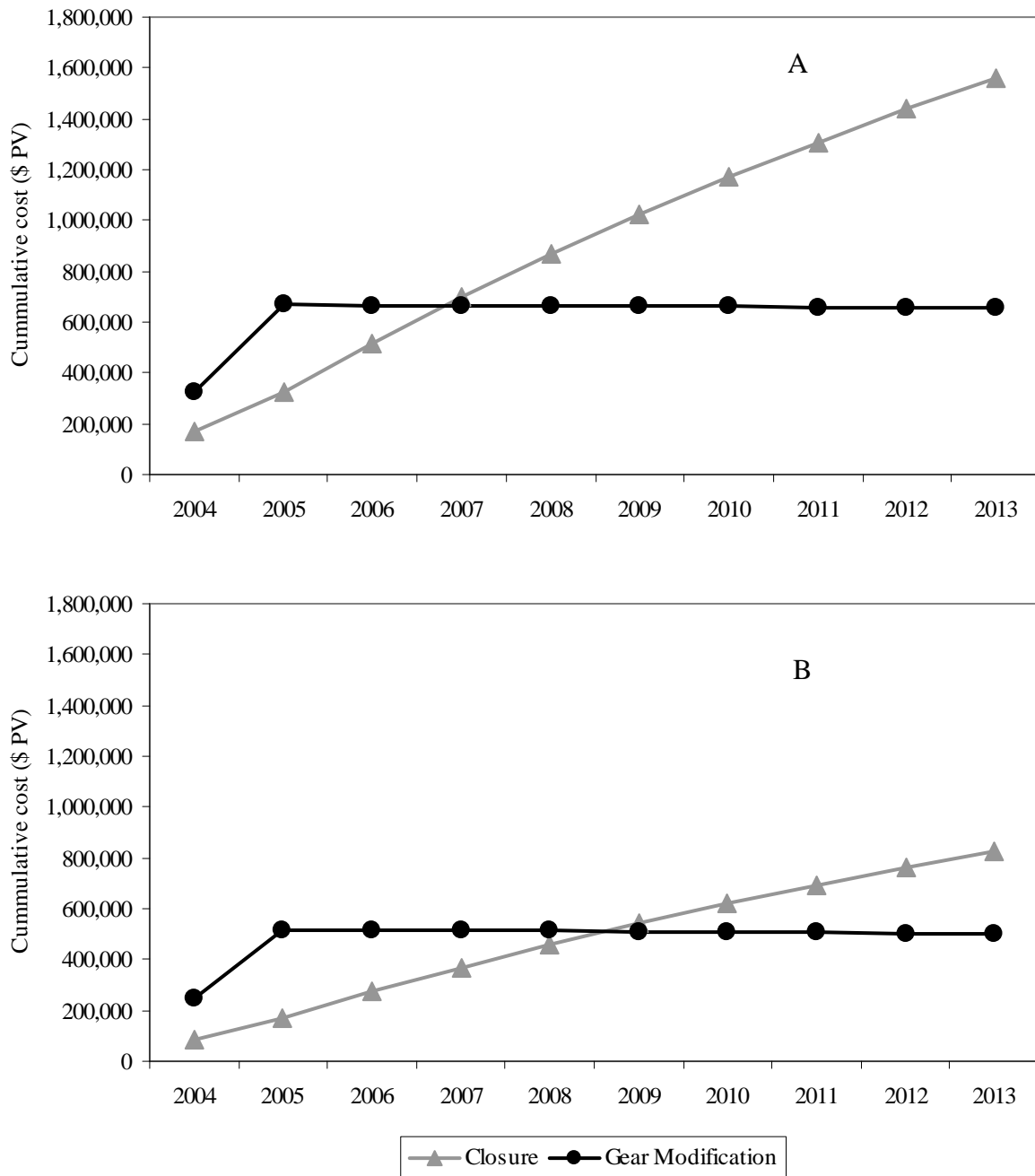


Figure 7. Cumulative present value of costs for closure and gear modification with a 7% discount rate and A) variable cost of fishing set to zero and B) variable cost of fishing at 50% of revenues.



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